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THE TERM REACTION TIME REDEFINED

By P. F. SWINDLE

For a particular simple or complex reaction, the cockatoo has at least as many reaction times as it is trained to have. By the term reaction time should be understood *the time which intervenes between the presentation of a stimulus and a response in which we are interested*. The natural reaction time to the stimulus green is too short for our modern instruments to measure; this is certainly the case with human beings, and we have no reason for assuming that it is any different with a bird. The most primary reaction to green is the immediate response to green, and not a certain movement we may be particularly interested in that succeeds the activity which is responsible for the psychical state of greenishness. We may say that the organism 'explodes' to green; we perhaps know of nothing more sudden than this explosive response. If we wish to demonstrate the existence of a different reaction time for the green-response, we may choose another stimulus—such as red; after the organism is stimulated for some time by red, it responds as if it were stimulated at this late period by green rays. This occurs while the eyes are open, and in spite of the fact that the stimulus red is all the time present. We may assume that, as is the case with human beings, the red grows less and less saturated and finally gives way to green. If the cockatoo is inclosed in darkness for a very short time after it has been stimulated for a few seconds by red, it responds in this case also as if to a green stimulus. Moreover, if it happens to close its eyes after it has been stimulated for a few seconds by red, it responds as if to green.

The cockatoo was trained to beat a particular group of movements, a unitary group¹ containing five elements, which was beaten in a particular tempo, (0.40 sec.) amplitude, and direction of movement when suddenly stimulated by flashing a searchlight through green glass. I shall call this a 5-group (5-g). The bird did not beat the 5-g when the light was flashed on it through a red glass; it was not trained to beat

¹For information concerning the "unitary group of movements," see my experiments "Ueber einfache Bewegungsinstitute und deren künstliche Beeinflussung," *Zeitschrift für Sinnesphysiologie*, Bd. 40, 1915

the 5-g as a conclusion to the immediate response produced by the red flash. Nevertheless, when it was illuminated for about ten seconds through the red glass and then the light was extinguished, making the room considerably darker thereby, the 5-g was regularly beaten. It evidently beat the 5-g after the green appeared as an after-response to the stimulus red.

It was accidentally observed that when the cockatoo was placed near an electric light and left unmolested until it became very quiet and closed the eyes for a period of many seconds, it almost invariably beat the 5-g very shortly after the eyes were opened. This response occurred whether the light was removed or not. I assumed that as long as the eyelids were closed, the cockatoo responded to the blood red of the illuminated blood-saturated eyelid, and that when the bird opened the eyes—thereby removing the stimulus red—it responded as if to green, i.e., the green occurred as an indirect response to the stimulus red. The responses occurred according to the following serial order: red-response, green-response, 5-g. The reaction time of the 5-g was determined by the time required for certain red- and green-responses to occur. This time was considerably shorter when only the stimulus green was used. This is in truth, such a remarkable series of responses that we must concern ourselves further with it. In the first place *we must ask ourselves what the essential differences between the red-, the green-, and the 5-responses are.* We will often find it valuable to use the term *group* instead of *response*. Our series would then read, red-group, green-group, 5-group. We must furthermore ask ourselves the question, *why it is that green-groups follow red-groups, and vice versa.* We know that the bird was trained to conclude the green-response with the 5-response or 5-group. *Is it not then logical to assume that red-groups are concluded soon by green-groups and vice versa because the animal has been trained to respond thus?*

Before going further, we may profitably discuss the training method which can serve to bring about such an alternation of responses as that of the red- and green-groups, and demonstrate its efficiency in any and every field of behavior. While this will be essentially a discussion of a training method, we will find ourselves continually concerned with the problem of reaction time.

The particular training method we shall now discuss is applicable to every field of activity, however simple or complex the responses in question may be, and regardless of the complexity of the subject to be trained. A few illustrations with

which every one of us is acquainted are as follows: a person smokes a cigarette and thus stimulates himself with the unusual stimulus tobacco smoke. The complicated response thus produced I shall call simply the tobacco-response. The person does not continue smoking the first time, but as to why he does not smoke one cigarette after another in rapid succession, I will not take time to discuss here. He makes a pause for the tobacco-activity, and during this pause other activities occur and become associated with the tobacco-response so that later, when the tobacco-response occurs, the second activity follows it. Whenever any two activities occur simultaneously or in a juxtaposed order, they thereafter occur more frequently in the same order. It is necessary that the adequate stimulus for only one of these activities act upon the organism, in order for both of them to occur. *The activity which is produced directly by the stimulus is an instinct; the indirectly produced one is a habit. The reaction times of instincts approach the zero value. An instinct is a response which follows immediately upon the presentation of its most adequate stimulus—and no other activity intervenes. A habit is a response which has at least one reaction time that is determined by the number and tempo of the elements of the one or more activities which intervene between the presentation of the stimulus used and the occurrence of the habitual response in which we are interested.*

When the first cigarette is smoked, at least two habits become established. The activity which by mere chance concludes the tobacco-response occurs hereafter more frequently than originally because it is now produced, not only as an instinctive response, that is, not only directly by its most adequate stimulus, but also indirectly by the stimulus tobacco-smoke. Likewise, the tobacco-response is now, not only an instinct, it is produced not only directly by the stimulus tobacco smoke, but also indirectly by the adequate stimulus for that activity—whatever this may happen to be—which terminates just as the tobacco-response begins. Later, whenever this stimulus occurs it produces directly its instinctive response which is concluded with the tobacco-response even though no tobacco smoke is present. This means that the person later responds more frequently than originally as if to tobacco smoke. He responds habitually to tobacco smoke.

If the person makes no pause for the tobacco-response the first time he smokes, this response will be in a high degree forgotten. The organic structures which the tobacco smoke excites to function can not function indefinitely. A pause inevitably comes, and if the stimulus remains always present,

not only while the activity is being carried out, but also during the recuperation pause for the structures in question, the stimulus becomes ineffective. I shall assume that it becomes ineffective because the structures which it ordinarily affects become highly exhausted, even though only temporarily. If a pause is produced artificially by removing the stimulus before the structures become in any great degree exhausted, the recuperation pause for the structures need not be very long. One essential condition that a person must fulfill in order to acquire the tobacco habit, is that he makes an adequate recuperation pause (for the structures the tobacco excites to action) before these structures become in a high degree exhausted. Another condition is that he applies the stimulus tobacco smoke each time he responds as if to this stimulus in its absence, otherwise there will occur that phenomenon of forgetting in time—or in other words, he will in the course of time become more active in other ways.

The same is true with the activity produced by fire which I shall call the fire-activity, or the fire-response. The person is active in a given way, at the conclusion of which he burns his finger with a flame. The complicated fire-response occurs and a pause is brought about for it by plunging the finger in water. Afterwards the person fears the fire, or in other words responds as if to fire when only the adequate stimulus for the preceding activity is presented. It is no longer necessary for him to place his finger in the flame in order to fear the fire; the fire-response is brought about, not only when its most adequate stimulus acts, but also sooner or later, whenever the adequate stimulus for an entirely different activity is presented to the body.

If the proper adequate recuperation pause is each time brought about before the responding structures become in any very high degree exhausted, the finger can be so trained that the physiological effects of the responses brought about either more or less directly by a slightly warm stimulus or indirectly by any other stimulus, may be so destructive that the finger will fall away. If, however, the finger is held close to the fire after it is burnt, the fire-response becomes forgotten as the structures which respond gradually become exhausted, and accordingly dissociated.

If the foot becomes very cold, and is gradually warmed, no harm results; while if it is brought suddenly near the fire, the fire-structures which have had their unusually long recuperation pause, now function so very strongly that the physiological effects may be almost the same as if the foot

were really placed in the fire. When the foot is for a long time subjected to the cold stimulus, the cold-response becomes forgotten while the structures for the fire-response are having their long recuperation pause. If the proper training method is applied to the foot, it can be caused to respond alternately as if to fire and ice, either when the adequate stimulus for one of these responses or when that for any other one that is associated with the fire- or ice-response, is presented. The essential condition which must be fulfilled in order to obtain such an alteration of responses is, the adequate pause for one must be filled in with the other response. This is possible only when each of the two responses is at least as long as the adequate recuperation pause for the other.

Ordinarily an indirectly produced response or habit is weaker than an instinct or directly produced response; but if the organism is carefully trained and care is always taken to make the recuperation pause sufficiently long, the habit may be just as strongly expressed as if it were brought about by its most adequate stimulus. For an example we choose a certain unprotected area on the body's surface at which two somewhat blunt compass points of wood can be detected as two when these stimulate points on the skin separated by a distance of two centimeters. A 5 square centimeter tactual stimulus consisting of the same material as the compass points is pressed over this area and allowed to remain 5 seconds, then a pause of 30 seconds is made before the stimulus is again applied, and so on.

Often, after only a few days' training, it is observed that the compass points now, in order to be detected as two, must be farther apart than two centimeters. As long as both stimulate points within the trained area, they are frequently perceived as one indefinite surface. This can mean nothing more than that the 5 square centimeter tactual stimulus brings about simultaneously very similar tactual responses over the entire 5 square centimeter skin area, and that these become so strongly associated in this particular order, i. e., in this temporally superimposed order, that later when a tactual stimulus produces directly one or only a very small number of these responses, such a great number of others are produced indirectly on neighboring areas that a second compass point is, as a stimulus, quite superfluous. The previously established cutaneous pattern is revived by the compass point, which is a comparatively insignificant stimulus. Careful observation teaches that the indirect responses do not occur as suddenly as the directly produced ones; but this time interval

is so very short that it is almost negligible. We can make the statement that, at least in many cases after the direct responses are produced, many of the indirectly produced responses occur so readily that a second stimulus point of the same nature as the first, when this is applied to a neighboring trained area, is very soon a superfluous stimulus. Any stimulus is superfluous if it is applied to the body after the response which it ordinarily produces directly, is, as in this case, already being carried out. If the 5 square centimeter object continually stimulates the area, no habits are established, and on the contrary this becomes an ineffective stimulus; its responses become in a high degree forgotten. This is the case with those bodily areas which come continually in contact with the clothing. Mouth areas which stimulate the tongue have become ineffective as tactual stimuli for the same reason. The eyeball which stimulates the inner area of the eyelid has for the same reason become ineffective as a tactual stimulus. These areas respond normally to other tactual stimuli which are not identical with those which have become ineffective.

If we turn now to the retina, or in other words, to a bodily surface area which is for some reason or another invaginated, and too so well barricaded against foreign stimuli that it responds primarily to certain ether vibrations, these being the stimuli which normally penetrate the schlera, lens, and humors of the eye before reaching the sensitive area in question, we find that the same laws we have been discussing are also applicable in this case. The entire retinal area has often responded to produce the sensation of reddishness, for example, when the eye is closed and turned up to the sky, or perhaps to the sun, and now when the ether vibrations which bring these responses about directly, act on a limited portion of the retina, qualitatively very similar, habitual responses are produced on the neighboring areas; those portions of the retina which are not directly stimulated respond as if directly to the stimulus red.

When the eyelid, or in other words the stimulus red is removed, the retina is directly stimulated, often by one of the many yellows or blues of nature, but it is most often stimulated directly by any one of the great variety of greens of our vegetation. The green which we may at any time see may be any of those which range from greenish yellow to greenish blue. The red- and green-responses must then necessarily become associated in this juxtaposed order, and consequently when one is directly produced the other follows it as an indi-

rectly produced response or habit. The one activity ordinarily fills in the adequate recuperation pause for the other; thus an alteration of habit-responses is made possible.

The kind of red which we see with the eyelid closed depends upon the nature and the intensity of the light rays which strike the lid; if it is a very intense sunlight we see a reddish yellow, and under conditions of weak illumination we are often able to see a reddish blue. We should then be able to answer the question why it is that the final and most distinctive habitual response which follows any instinctive one produces the most dissimilar psychical state that we, as visual organisms, can experience. For example, the final indirect response to our common saturated red is our saturated green, and the final indirect response to this green is our saturated red.

When a person with closed eyes looks at the sun, and with the eyes still closed turns the head to a dark corner, or perhaps walks into a shady place, he sees a great variety of reds one after another. These reds become associated in this particular order. Moreover, when the observer, with the eyes closed, turns the face to the sun, or walks from a dark place into the intense sunlight, he may see every possible red—from a reddish blue to a reddish yellow. Associations are also formed in this direction. Consequently when the stimulus is our saturated red; this red is the directly produced response, and various reds as habit-responses then occur in the order determined by the length of their reaction times; those with the shortest reaction times occur first, and those with the longest reaction times occur last. This happens to be in the particular order of the similarity of the indirectly produced reds to the directly produced one; the most similar ones are produced first. For example, orange-red and violet-red have the same reaction times, with reference to the stimulus used, and are accordingly produced simultaneously and sooner than violet or orange which have longer reaction times. Since we have frequently seen various blues and yellows, as well as various reds and greens, no significant break occurs in our production of habitual responses; blue and yellow are next produced, then those with still longer reaction times, such as peacock and olive, and finally green.

During the greater part of this time the red-structures have been having their recuperation pauses, so if now the retina is stimulated in any new way, the red responses can be brought about most easily which means in greater numbers. Adequate stimuli for the green-responses are superfluous, because the structures are already responding as if to these stimuli. Fur-

thermore, the stimuli which are ordinarily adequate ones for such as the peacock- and olive-responses are ineffective, because their structures are highly exhausted. If, simply because the visual structures cannot respond in any other way, the red-responses chance to follow the green ones, these become associated in this juxtaposed order. The same thing need only occur when we use any particular green as a stimulus instead of red in order to get an alternation primarily of the red- and green-responses, in which case many of the earlier temporally intervening responses become isolated from or eliminated from the 'red-green-series' in question. We may say that they become dominated over by the red- and green-responses.

A sufficient number of these intermediate responses will always occur, however, to cause the two alternating responses to always be those which are accompanied by the most dissimilar visual psychical states.²

If we now turn to the unitary group of movements, we find that these behave in the same way. When two groups occur simultaneously or in close succession, the tendency is manifest for them to occur hereafter frequently in this superimposed or juxtaposed order when the adequate stimulus for only one of these is presented. Temporally superimposed habit-groups have as a rule a very short reaction time. It is for this reason that we use the term temporal superposition instead of simultaneity of occurrence. The directly produced and indirectly produced responses do not start simultaneously, but at least a part of both occur simultaneously. A few elements of the first activity may be beaten before the indirectly produced response begins.

The reaction time for the activity of a cockatoo's crying will now be our immediate subject for discussion. This is an activity, i.e. a group of movements, the adequate stimulus for which is unknown. I will therefore call it x. When the fingers were snapped in a particular way, it was noticed that the bird quickly nodded the head and then immediately afterwards uttered a shrill cry. The reaction time was in this case about 0.60 sec., and it was determined by the temporal duration of the head movement which intervened between the presentation of the stimulus and the cry. The finger snap was not the most adequate stimulus for the cry, but for the head

² What is here stated concerning color vision, while it may give some general hints as to the nature of the theory of vision which I shall discuss in a later manuscript, should be looked upon merely as a discussion of the problem of reaction time.

movement which had, at some time or another, become associated with the activity of crying.

The cockatoo, without having been trained to do so, beat occasionally among other unitary groups, a 7-g in the tempo of 0.77 sec. Each element of this group was a sudden stroke of the beak in the air. I choose to make this group a habit. I accordingly merely observed the bird until this particular group was beaten, and then I placed the animal on the floor and allowed it to walk about for one minute. Then I placed it on its perch (the place where it usually beat movements in this tempo) and snapped a stop-watch. The bird responded to this stimulus by suddenly jerking the body. This usually resulted in the bringing of the body, suddenly, into a more erect position. Whenever the bird did not happen to be stimulated in such a way that it beat the desired 7-g just after the body was so jerked, I snapped the watch repeatedly at intervals of five seconds until the 7-g did chance to appear very soon afterwards. When this occurred, a pause of one minute was again made for the 7-g. After this was done a few days the bird regularly beat the 7-g a very short time after the watch was snapped. The only observable activity that intervened was the jerk of the body. The 7-g was thus made a habit. It was now produced not only by its most adequate stimulus, which is unknown and which I will therefore call y, but also indirectly by the watch snap.

After the 7-g had become a well established habit, I snapped the watch, the body was straightened, the 7-g followed, and as soon as this response was finished I snapped my fingers, and then occurred a quick nod of the head, and following it the cry. This chain of activities became so well associated in the order of jerk of the body, 7-g, nod of the head, cry, that when I snapped the watch after an adequate recuperation pause had each time intervened, the responses almost invariably occurred. The reaction time of the cry was in this case, as determined by the stop-watch, 5.36 seconds. Roughly estimated, this time was divided among the various groups of the chain as follows: 0.20 sec. for the straightening of the body, 4.62 sec. for the 7-g, and on an average 0.81 sec. for the nodding of the head, and the very short time which intervened between this movement and the last element of the 7-g.

The activity of crying was a habit-group to begin with; for it was already invariably preceded by the nod of the head. It became merely a more strongly established habit when it became associated also with the 7-g. It finally became produced not only directly by its most adequate stimulus x, and indi-

rectly by the stimulus finger snap, but also indirectly by the y and the watch snap. The activity of crying accordingly occurred more frequently than previously. The training method was further applied to associate a great variety of groups with the 7-g which was regularly followed by the nod of the head and the cry. The reaction time of the cry could with a high degree of certainty be predicted if the stimulus 'only' was known. It was merely necessary to consider the number and tempos of the movements of the various groups which regularly intervened between the presentation of the stimulus used and the occurrence of the cry.

Generally, when any unitary group is beaten, and an adequate recuperation pause for it is made, during which the animal is not allowed to beat any group in the same tempo, this group is the first one to be beaten after the pause. Since this is the case, the likelihood that the direct response to the stop-watch which snaps every five seconds will chance to be concluded just as the activity of our primary interest begins, is very much increased. The watch must not be snapped incessantly. If it is so snapped, it will become ineffective for bringing about even its most immediate response. The observed immediate response to this stimulus was very short (about 0.20 sec.) and the adequate recuperation pause was also very short, the pause being not longer than three seconds. It was therefore possible to snap the watch every five seconds without exhausting the structures which were responsible for the produced visible activity. If this direct response to the snap of the watch happens to be concluded just as the 7-g—or just as some activity which is associated with the 7-g—starts, the association is, as we have seen, more or less definitely established.

Since the most complex activities, such as the fire-, ice-, tobacco smoke-, green-, red-responses, etc. behave in just the same general way as the simple unitary groups, I have ventured to postulate the group-movement as the behavior correlate of every psychical state.

The fire-response I have spoken of as complicated. This merely means that a great variety of unitary groups are being beaten simultaneously, and serially. The stimulus fire produced directly a great number of groups, a large number of which are qualitatively similar, even though they may be quantitatively very different. They are qualitatively the same since they are beaten in a constant tempo, direction, and relatively constant amplitude of movement, and they are quantitatively the same or different in the sense that they contain

the same or different numbers of elements. For example, one of these postulated groups may contain two elements in the tempo of a hundredth of a second, and another which is beaten in the same tempo may contain fifty elements. The duration of the latter group is twenty-five times that of the former. Let us say that the 2-g is associated with a particular activity which may be called the a-response, and that the fifty-group is followed regularly by another response which may be called the b-response. The reaction time of the b-response would accordingly be twenty-five times that of the a-response; and if these groups start simultaneously, they cannot terminate at the same time.

I have ventured to speak of the behavior correlates for colors, such as red, in terms of the unitary group. I have called these the red-groups. These are qualitatively similar, but they may be widely different quantitatively. If we then fixate a piece of red paper, the stimulated visual substances beat the red-groups in great numbers. These are temporally superimposed. The shortest ones terminated must have their adequate recuperation pauses before they can be beaten a second time. And they may occur a second time before the longest red-groups are completed, i. e. provided the stimulus remains present. With any red-group there may be associated any other response. Of the possible visual responses which may be associated with the different red-responses, may be mentioned the blue-, yellow-, orange-, violet-, peacock-, olive-, green-groups, and so on. The qualitatively most dissimilar groups, i. e. the green-groups, may be associated with the longest, or under conditions, the shortest, or medium red-groups. In other words, the reaction time of the green-groups as habits may be anything the visual organism may be trained to have. The eye appendages such as the eyelid, lashes, etc., serve to make this reaction time short. This and many other things which a theory of visual sensations should explain, will be brought out in a later manuscript on "Visual Instincts and Habits."